Internet of Things and M2M Communications as Enablers of Smart City Initiatives

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***Abstract*—This paper describes Internet of Things (IoT) and Machine-to-Machine (M2M) communications as the enablers of smart city initiatives. The challenges in modern cities are briefly identified. Utilization of IoT based applications and services could mitigate these challenges. The paper then introduces an architecture based on oneM2M standards for smart cities. The key elements of the architecture are described along with the common service functions. The main contributions of the work are – (i) uniform metadata exchange with things using Sensor Markup Language and its extensions, (ii) uniform description of heterogeneous things for configuration management, (iii) OMA Lightweight M2M based device management framework, (iv) resource discovery framework and (v) Machine-to-Machine Measurement framework based M2M data processing and analytics. The core functionalities of these frameworks are exposed to the consumers through RESTful web services. An application scenario on crowdsourcing in the smart cities is highlighted. Finally the paper concludes with future research directions.**

Keywords—Discovery; Device management; IoT; oneM2M standards; Smart city; Crowdsourcing.

I. Introduction

It is estimated that the world population is set to grow by an estimate of 2.3 Billion by 2050 and 60% of the population will reside in cities[1]. This will increase the challenges on city infrastructures for managing mobility, public safety, resource & waste management etc. To provide better services and improve the quality of life of citizens, the cities are currently under transition towards a higher quality of living, next-generation ICT enabled services, intelligent energy management and resource efficient economy. ICT plays a critical role in envisioning, developing and maintaining “smart cities”.

A plethora of such ICT activities are taking place on a wide range technologies including cloud and network edge computing, sensing and actuation, low power communication protocols, big data analytics and smart healthcare. They can be united under the umbrella of M2M communications and Internet of Things [8]. They bring together citizens, industries, governments and provide applications and services that encompass intelligent transportation systems, building automation, smart healthcare, smart grid and more. These IoT based applications have three fundamental operations - (i) M2M data collection from sensors, (ii) M2M data processing to generate high level abstraction and actionable intelligence and (iii) ability to react and actuation based on the derived intelligence [1]. But achieving that is not quite simple due to several challenges: (i) heterogeneity and multimodality of the physical things, (ii) lack of unified management framework of the connected things, (iii) high mobility, (iv) adequate discovery mechanisms of IoT resources, (v) M2M data processing framework, (vi) lack of standardization efforts and (vii) security.

The smart city applications and services germinate from these challenges and requires defining several frameworks to realize the vision of smart city initiatives [4] [5] [6] [7]. In turn, these frameworks must be interoperable, provide a means for discovery and metadata exchange regardless of communication technologies. The basis of such vision is effectively created by Internet of Things which will not only includes M2M communications but also Machine-to-Human (M2H) interactions through mobile applications. In this paper we describe several such frameworks and APIs to address the mentioned challenges. Finally the smart city application scenarios are composed of three categories – infrastructure, M2M data analytics and mobility. The infrastructure includes the physical hardware elements, e.g. M2M devices (sensors and actuators), M2M gateways, test beds, cloud data centers. Out of that, the M2M devices essentially form the data generation blocks of smart cities. The M2M data analytics encompasses several functionalities namely representation, aggregation, processing, storage and retrieval of M2M data. It goes through various treatment at various stages of the smart city applications. Finally mobility takes care of issues like management of M2M devices which can be both static and mobile.

The rest of the paper is organized as follows. Section II presents a smart city architecture based on oneM2M standards. Section III describes the components of the architecture. Section IV highlights crowd sourcing as an application scenario for smart city and Section V concludes the paper.

II. oneM2M Based Smart City Architecture

While designing and developing an architecture for smart city initiatives, we must select a standard architecture. This will promote interoperability among the IoT components and provide a set of guidelines to develop consumer applications.

[1] http://www.cisco.com/web/strategy/docs/gov/everything-for-cities.pdf

We have presented oneM2M based architecture since this is the first global architecture for M2M and IoT [13].

The architecture components are broadly classified into field and infrastructure domains as portrayed in Figure 1. The elements of each domain are composed of Application and Common Service entities. An Application Entity (AE) contains the application logic for the end-to-end M2M solutions e.g. home automation, fitness monitoring, intelligent waste collection. Each AE must have a unique identity. A Common Service Entity (CSE) represents a set of common service functions (CSF) of the M2M ecosystem. CSF includes discovery, M2M device management, data management & repository, security, group management, application & service layer management, location, subscription & notification. The CSF provides such services to both AE and other CSEs. An instantiation of CSE in any nodes comprises of a complete or subset of the CSFs presented in Figure 2.

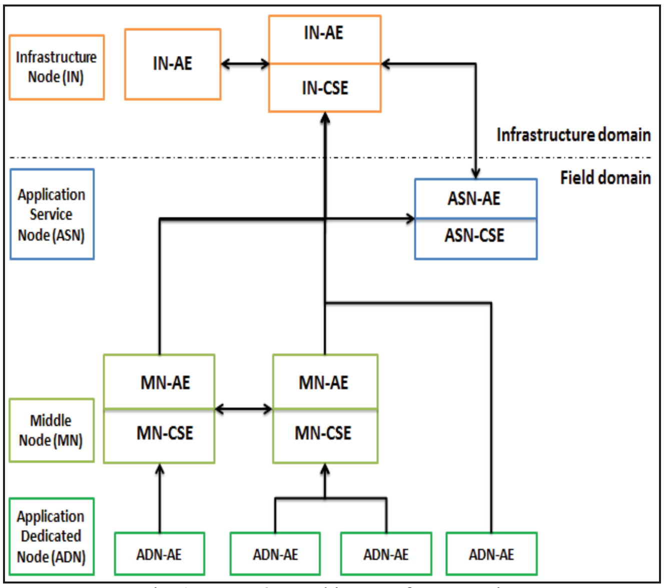

Fig. 1. oneM2M architecture for smart city.

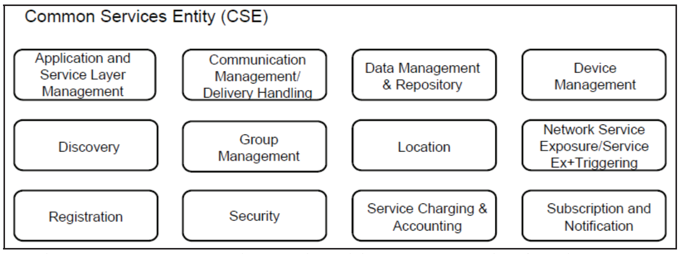

Fig. 2. A common services entity with common service functions [13].

The different nodes in the field and infrastructure domains are mentioned below.

- An application dedicated node (ADN) is a node that contains at least one AE and does not contains any CSE. ADN communicates with either middle node or infrastructure node.
- An application service node (ASN) contains at least one AE and a CSE. In this case, the ASN-AE and ASN-CSE are embedded into the mobile application running in the smartphones or tablets.
- A middle node (MN) contains only CSE and not AE. It communicates with an infrastructure node (IN) and an ASN. The M2M gateway corresponds to the MN.
- An infrastructure node (IN) provides an M2M service in the infrastructure domain. IN contains a CSE and none or more AE. This node interacts with one or more MNs and/or one or more ASNs. IN basically corresponds to a cloud system.

The prototype architecture of a smart city consists of physical things as ADNs which are interacting with a smart M2M gateway [1] [18] over M2M area network. The gateway is deployed to bridge the Internet with non-smart things and to act as data aggregation points. In the oneM2M architecture, it acts as MN. Several such middles nodes are registered to a central cloud system belonging to the smart city. The CSE in these cases comprises of resource discovery, device management, configuration framework, data repository, notification & subscription, proxy layers and M2M data processing unit.

III. Smart City Architectural Components

This section describes the components of the IoT architecture mentioned above which in turn helps realizing the vision of smart city initiatives.

A. Uniform data exchange with physical things

The physical things belonging to any smart city framework are heterogeneous in nature. At the same time, the data generated by the things are multimodal and represent different domains of diverse nature. A major share of the things will embed a microcontroller with very limited capabilities. This poses numerous challenges in uniform data exchange with sensors and actuators. This is solved using Sensor Markup Language (SenML) [16]. It provides a uniform and structured way to encode sensor measurement and additional attributes of the things (e.g. type of device, unit, timestamp, domain, update time). This creates a sensor metadata which forms the stepping stone M2M data processing. Using SenML, multiple sensors attached to an M2M device can be efficiently represented and communicated. A sample SenML light sensor metadata encoded using JSON is shown below. Apart from the light sensor measurement value 200, the metadata also contains the unit lux, name of the sensor (LS-1), software version 2.0 and type of measurement being illuminance. The time stamp is calculated with respect to 16/01/1970 AD at 23:34:57 UTC.

{"e":[{"n":"LS-1", "v": 200, "u": "lx", "t": "1380897199", "ver": "2.0", "type": "Illuminance"}]]

From an M2M server perspective, the lightweight and serialized representation of the metadata allows multiple SenML metadata to be parsed in parallel. This property of SenML makes the servers efficient and limit the use of M2M resources. Moreover, the metadata could be exchanged as a payload of RESTful interactions (HTTP or CoAP[2]). Therefore,

[2] https://tools.ietf.org/html/rfc7252

SenML solves the challenges related to sensors. At present there is no markup language available for uniform data exchange with actuators. We have extended the capabilities of SenML so that the same software implementation could be used with actuators also [12]. This is a unique aspect of this work. For actuators, the added attributes are – (i) name and ID of actuator, (ii) supported functionalities (e.g. on/off/dim a light switch), (iii) unit, (iv) allowed range of values, could be discreet (on/off for a light switch) or continuous (for a motor) and (v) location. Therefore, the main advantage is that a generic API implementing SenML and its extensions could be used to exchange uniform metadata with any types of things. This is beneficial for the application developers. It is also very easy to integrate the API into consumer mobile applications.

B. Uniform mechanism for configuration management

The inherent heterogeneity of the things also creates research challenges in terms of configuration management. Right now the thing manufacturers create a default configuration which might need to be updated based on the lifecycle of the things. Also the context and domain in which the thing is used may determine its configuration. Managing such operations for huge volume of heterogeneous things in a smart city requires the following – (i) a lightweight description of things and (ii) a uniform mechanism for configuration management. We utilize CoRE Link Format [17] to describe the things in terms of resources and attributes. A list of necessary function sets are tabulated below. The namespace of the resource type is used from IPSO Alliance framework.

TABLE I. LIST OF FUNCTION SETS

Function Set	Root Path	Resource Type
Configuration	/cf	ipso.config
Device	/d	ipso.dev
Endpoint	/e	ipso.endpoint

Each function is further expanded as shown below. Each M2M device contains endpoint(s) (sensors, actuators) and an initial configuration is stored in the device. This can be represented using XML or JSON. When a device registers itself to an IoT platform, this initial configuration is uploaded to the configuration management system. The function set "Device" provides the device resource description in terms of name, unique identification, model, location, destination, endpoint, proxy-out and proxy-in. The location could be described as semantic location, XY coordinates from a reference point or GPS coordinates. The proxy-in and proxy-out are our unique contributions and they assist in creating the descriptions of legacy things [18]. This in turn allows them to be a part of IoT ecosystems.

The M2M endpoints attached to a M2M device could be described in a similar fashion as shown in Table III. The interface definition (IF) parameter defines the RESTful interactions supported by a resource type. For example, Identification of a device can only be accessed with GET method and cannot be updated with POST or PUT. On the other hand, location of a device could be accessed using GET as well as created with POST and updated using PUT method.

TABLE II. M2M DEVICE RESOURCE DESCRIPTION

Type	Path	RT	IF
Location	/d/loc	ipso.loc.gps / ipso.loc.xy / ipso.loc.sem	p
Identification	/d/id	ipso.dev.id	rp
Name	/d/n	ipso.dev.name	p
Model	/d/mdl	ipso.dev.model	p
Endpoint	/d/end	ipso.dev.endpoint	p
destination	/d/dst	ipso.dev.destination	p
proxy-out	/d/po	ipso.dev.proxy-out	rp
proxy-in	/d/pi	ipso.dev.proxy-in	rp

TABLE III. M2M ENDPOINT RESOURCE DESCRIPTION

Type	Path	RT	IF
id	/e/id	ipso.endpoint.id	rp
name	/e/n	ipso.endpoint.name	p
device	/e/d	ipso.endpoint.device	p

The CoRE Link format based configurations are implemented using JSON. We have created an API which can automatically create the description in a smart thing. For a legacy thing, it is assisted by a proxy. The configuration file requires less than 1KB memory to store the above descriptions. This establishes CoRE Link Format as an efficient choice for configuration management in smart city. The JSON based API also promotes interoperability among other components of the smart city framework.

C. M2M device management framework

The deployment of IoT based platforms and services as a part of smart city infrastructure has not been that satisfying. One of the main reasons behind that is the lack of unified approach for M2M device management. The research challenges behind this stems from several facts like heterogeneous nature of M2M devices, mobility pattern of M2M devices, access control policies and lack of self-management mechanisms. We propose to utilize Open Mobile Alliance Lightweight M2M (OMA LwM2M) [14] to create a structured and lightweight framework for M2M device management. To promote interoperability, this CSF makes use of configuration management and proxies as shown below.

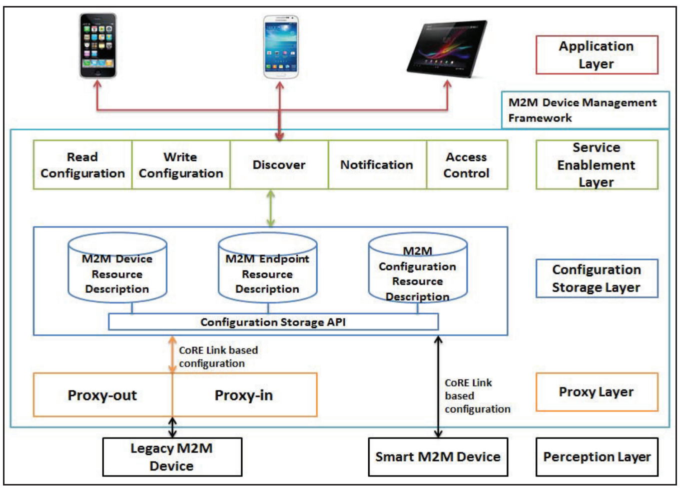

Fig. 3. OMA LwM2M based M2M device management framework.

The framework employs the proxies to assist legacy devices whereas the smart devices could automatically upload their configurations to the configuration storage layer. There is an API which extracts the device, endpoint and configuration resource descriptions and translates them into appropriate storage format. The registration mechanism is quite simple and the operational flow is depicted in Figure 4. The registration requests, reply and uploading the configurations are achieved over RESTful interactions. This is possible since the entire framework is developed using web services.

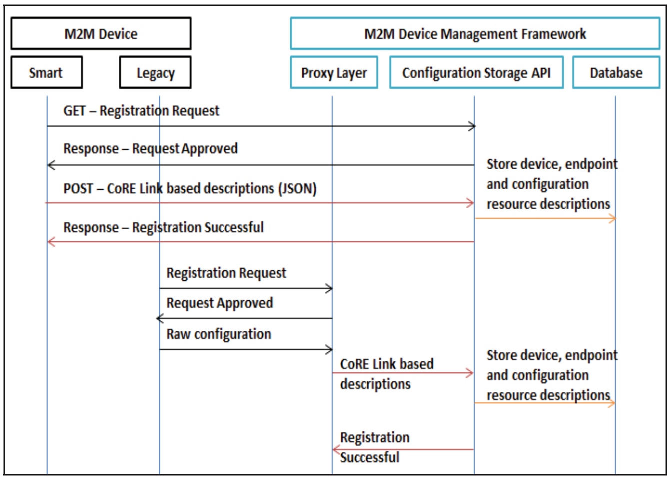

Fig. 4. M2M Device registration phase.

The consumer centric functionalities like read, write, update and deletion of configurations are also exposed using web services. The framework also enforces access control policies [9] [10] [11] to limit the access to authorized M2M devices. A unique feature of the framework is lifetime attribute. After the registration phase, each M2M device must announce itself periodically to the framework otherwise its configuration is deleted. This period is defined as the lifetime attribute which enables automatic management of devices. This is particularly useful to track mobile M2M devices.

D. Resource Discovery

To provide value-added services to consumers, M2M devices must interact with the environment and among themselves to exchange metadata, process metadata and react automatically. To realize this vision of IoT, proper discovery mechanisms should be provided [2] [3] [24]. We describe a resource discovery framework (in Figure 5) which provides a look up facility to search for M2M devices, their properties & capabilities and URIs to access them directly. The novel aspects of the framework are: (i) search engine integration and (ii) discovery of M2M devices regardless of communication technologies and their smartness. The functionalities of the proxies are further augmented so that the proxy layer can communicate to a wide range of technologies (NFC, BLE and Zigbee). The discovery layer makes use of the configuration management related components. To ease the search procedure, the configuration descriptions of the registered M2M devices are indexed. These indices and the URIs of the devices are stored in a separate database. The core discovery functionalities are exposed to the consumers and other IoT applications through RESTful web services at the service enablement layer. The discovery request is processed by the search engine. It intelligently extracts key parameters and initiates internal search. Upon completion, if any matches are found, the URIs to those M2M devices along with their properties and capabilities are replied to the requestor. Similar to the management framework, this module is also dependent on access control policies to limit the discovery to authorized devices.

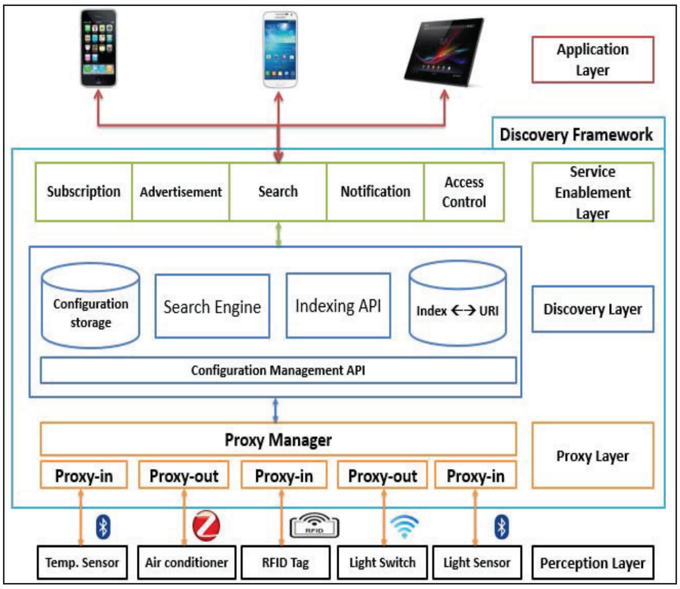

Fig. 5. Resource discovery framework.

E. M2M Data Processing and Analytics

The sensors deployed in the smart city infrastructure will generate data. Existing research works identify that providing interoperability in generated M2M data and their interpretation poses numerous challenges for IoT application developers. Another important aspect is that these M2M devices operate in a highly distributed and autonomous fashion. Therefore M2M data aggregation and combing data from several source become another challenge. Yet M2M data processing and analytics allows the M2M devices to react to the environment automatically through actuation. Semantic web technologies can address these challenges. To explicitly describe sensor data and reason on them, such technologies are used. The ontologies can ease the semantic reasoning process by integrating rules and inference engine can reason on sensor data. This work utilizes Machine-to-Machine Measurement (M3) Framework [15] [19] [20] which not only addresses the challenges mentioned above but also enables developer in building cross domain IoT applications. This is achieved by combining the multiple sensor data generated in multiple domains. M3 framework includes M3 nomenclature and M3 ontology which provide a common vocabulary catalogue for M2M devices, measurements etc. A unique contribution of M3 is that it provides an interoperable mechanism to interpret sensor data. The M3 architecture is presented in Figure 6. It has been discussed in depth in [19]. In this section we describe the operational flow of M3 framework. The operational flow is explained using Figure 7. Existing IoT and Semantic Web of Things (SWoT) application are not interoperable with each other due to heterogeneity in things, communication protocols etc. Therefore a major challenge for the IoT platforms would be to assist developers in creating interoperable applications and services. The M3 framework addresses the challenges of: (i) interoperable M2M data, schemas and domains, (ii) semantic based interpretation of M2M data and (iii) generation of interoperable IoT/SWoT applications.

To assist developers in building such applications, the SWoT Generator has been conceived. This tool generates an M2M template which includes necessary M3 ontologies, M3 datasets and M3 rules needed to interpret and enrich M2M data with domain knowledge to build applications. The generator takes the sensor (e.g. temperature) and the domain where it is deployed (e.g. weather) as inputs and provides the template to the developers. The next step is to semantically annotate the IoT data. This step utilizes the M3 nomenclature and the M3 converter to make IoT data coming from heterogeneous sources interoperable with each other and explicitly add the context. The M3 converter is compliant with the Sensor Markup Language (SenML) format in terms of sensor metadata description but could be extended to support other formats. The treatment of this phase generates M3 IoT data compliant with the M3 domain knowledge. Finally, to interpret IoT data, Linked Open Vocabularies for Internet of Things (LOV4IoT) has been designed to reuse domain knowledge already designed by domain experts. More than 200 domain knowledge relevant for IoT have been referenced, studied and classified. Stemming from the 'Linked Open Data', the Sensor-based Linked Open Rules (S-LOR) has been designed to share and reuse interoperable rules to easily enrich IoT data by reusing domain knowledge from LOV4IoT. Due to interoperability issues, the M3 domain knowledge has been rewritten and is composed of interoperable ontologies, datasets and rules to enrich IoT data and provides inter-domain interoperability to easily build IoT applications.

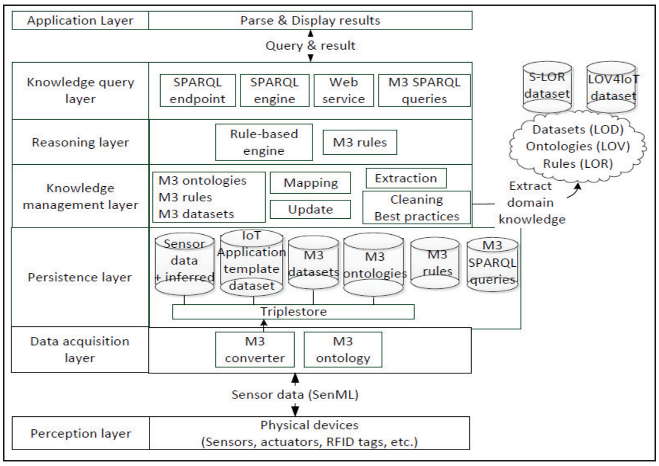

Fig. 6. Architecture of M3 framework.

The M3 framework is implemented using Apache Jena Framework and is deployed in a cloud system. This is suitable for the smart city initiatives.'

These above components are the CSFs mentioned in section II and can be instantiated in both middle node and infrastructure node. The AE depends on the logic of the application being implemented. The discussions in this section establish the CSFs as indispensable part of any IoT platform and smart city framework.

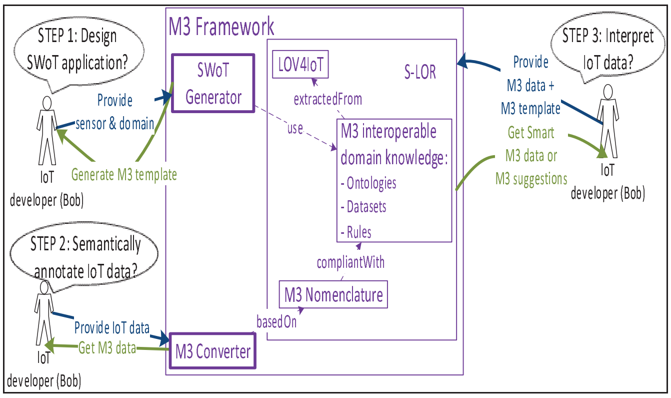

Fig. 7. Operational flow of M3 framework.

IV. Crowdsourcing in Smart City

Crowdsourcing is an important use case for smart city [21] [22] [23]. This section highlights how smart city crowdsourcing scenarios can benefit from the proposed oneM2M architecture.

For such services, the M2M devices such as sensors, RFID tags, things with bar codes etc. could act as sources of information. As a result, these devices constitute the ADNs. Things that are capable of IP communications may directly communicate their data to the smart city cloud (IN) while legacy things are assisted using intermediate gateways or proxies. Certain crowdsourcing services offer local processing of data. This can be done by deploying M2M gateways (MN) and the CSE components at the gateway will provide local data processing mechanism. The high level abstraction inferred from the raw measurements will be communicated to the cloud. The metadata from the devices are exchanged using SenML and its extensions. For unified device management and resource discovery, the uniform configuration management module will be used. The discovery module is used by consumers to look for appropriate services necessary. The cloud system gathering all the metadata is able to process them using M3 framework. The resulting intelligence could be pushed back to the devices or authorized users can be notified in their mobile phones [12]. For smart traffic solutions, crowdsourcing could offer real time traffic update enabling drivers to change the route to destination if necessary. User centric applications could be developed for smart city crowdsourcing following the guidelines mentioned in [25].

V. Conclusion

This paper initially analyses the current landscape of cities and their growing challenges. M2M communications and IoT applications and services are mentioned to address these issues and act as pillars to create the envisioned smart cities. But it is identified that IoT itself has numerous issues. To address them, the paper proposes a smart city framework and oneM2M architecture to implement the framework. The key components of the architecture are discussed in depth. Finally crowdsourcing use case for smart city is outlined which uses the proposed architecture and its components. As of future work, we are in the process of deploying the architecture to real world to realize the use case on crowdsourcing.

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